



Frost-Susceptibility Testing and Predictions for the Raymark Superfund Site

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Abstract: This project was conducted to assist in predicting the effects of freeze-thaw cycling on Tilcon common granular fill during the freezing season. This material is being used as the subbase material in the proposed pavement structure at the Raymark Superfund site in Stratford, Connecticut. Based on the initial laboratory results of the Tilcon material performed at CRREL, the amount of fines passing the no. 200 sieve was found to be in the vicinity of 20%, of which approximately 14% was finer than 0.02 m. Results from the frost heave tests indicate that when the Tilcon

material is saturated, based on the rate of heave, the material is classified a high to very high frost-susceptible material. In the saturated condition, the material is classified as a low to medium frost-susceptible material. Computer simulations were run to predict the amount of frost heave and frost penetration that may be expected on this site during the freezing season. Results from the laboratory frost-susceptibility tests and computer simulations were then used to estimate the amount of cumulative damage to the pavement structure during its design life.

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PREFACE

This report was prepared by Dr. Vincent C. Janoo, Research Civil Engineer, Lynette A. Barna, Civil Engineer, and Sherri A. Orchino, Civil Engineering Technician, Civil Engineering Research Division, Research and Engineering Directorate, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire. Funding was provided by the U.S. Environmental Protection Agency (EPA) through the U.S. Army Corps of Engineers, New England District (NED).

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EXECUTIVE SUMMARY

CRREL was approached by the Geotechnical Engineering Division of the New England Division (NED), U.S. Army Corps of Engineers, to assist in predicting the effects of freeze-thaw cycling on pavement design during the freezing season on Tilcon common granular fill. This Tilcon common granular fill is being used as the subbase material in the proposed pavement structure at the Raymark Superfund site in Stratford, Connecticut. The Tilcon material is considered to be a clean material that comes from a source in North Branford, Connecticut.

Based on the initial laboratory results of the Tilcon common granular fill material performed at CRREL, the amount of fines passing the no. 200 sieve was found to be in the vicinity of 20%, of which approximately 14% was finer than 0.02 mm. Results from the frost heave tests indicate that when the Tilcon material is saturated, based on the rate of heave, the material is classified as a high to very high frost-susceptible material. In the unsaturated condition, the material is classified as a low to medium frost-susceptible material.

Four computer simulations were run to predict the amount of frost heave. Two of the simulations used a Tilcon subbase layer of 640 mm and varied the depth of the water table to 100 mm below the pavement surface, simulating a saturated soil, and a water table depth of 2740 mm for a soil containing low moisture. The remaining two simulations used the same water table depths, but decreased the layer of the Tilcon subbase to 460 mm.

Overall, the computer simulations predicted frost heave levels of 45 and 47 mm with saturated soil for the 640- and 460-mm subbase thicknesses, respectively, and significantly lower levels of frost heave with moist soil (5.3 and 6.7 mm). The amount of frost penetration for saturated soils was 320 and 340 mm for the 640- and 460-mm subbase thicknesses, respectively. For the moist soil, the frost penetration reached a maximum of 560-mm depth. For both simulations using low moisture content soil, the frost penetration depth only reached approximately halfway into the Tilcon common granular fill material layer.

Frost-Susceptibility Testing and Predictions for the Raymark Superfund Site

VINCENT C. JANOO, LYNETTE A. BARNA, AND SHERRI A. ORCHINO

INTRODUCTION

CRREL was approached by the Geotechnical Engineering Division of the New England Division (NED), U.S. Army Corps of Engineers, to assist in predicting the effects of freeze-thaw cycling on pavement design during the freezing season on Tilcon common granular fill. This Tilcon common granular fill is being used as the subbase material in the proposed pavement structure at the Raymark Superfund site in Stratford, Connecticut. The Tilcon fill, considered to be a clean material, comes from a source in North Branford, Connecticut.

The Raymark Superfund site is currently under remediation with the intention of using the reclaimed land for commercial development. A portion of the site is planned to be used as a parking area. The pavement structure of the proposed parking area will consist of a total of six layers of material. The uppermost layer will be composed of approximately 76 to 102 mm of asphalt concrete. Below this, a maximum of 203 mm of graded granular base will cover approximately 610 mm of Tilcon common granular fill. Geosynthetic liner materials, approximately 30 mm thick, will be placed between the Tilcon material and a sand gas collection layer (203-mm thickness). The undermost layer consists of waste material, which is a mixture of on-site soil combined with the hazardous waste that was produced on site. Asbestos, lead, PCBs, volatile organic compounds (VOCs), semi-VOCs, and solvents have been detected in the on-site soil. This mixture was

treated with 3.5% cement and compacted prior to placement of the geosynthetic liner materials.

The investigation performed by CRREL is based on the projected performance of the pavement structure for both a short-term and a long-term basis. Factors associated with the pavement's performance over a long-term period include the types of soils used in the pavement structure, cracking due to loading and temperature changes, and moisture infiltration from the surface, as well as the location of the water table below the surface. The time period of interest is during the freezing season when frost heave is most damaging to a pavement structure.

CRREL conducted laboratory frost heave tests to index the frost-susceptibility of the Tilcon common granular fill. CRREL's task included predicting the amount of frost heave for the pavement structure. The computer model, FROST, was used to predict the amount of frost heave for the simulated pavement structures. All of the structures used the same material characteristics and number of layers. The first structure included a Tilcon subbase thickness of 640 mm, and the second structure used a Tilcon subbase thickness of 460 mm. A third set of simulations was run in which the graded base was increased from 203 mm to 560 mm. The last set of simulations was tested to estimate the life of the structure based on the design loads.

This report discusses results from both the laboratory frost heave tests completed on the Tilcon common granular fill and the computer simulations.

FROST HEAVE

Frost heave, or the raising of the surface layer because of ice in the subsurface, is detrimental to pavement structures. By increasing the amount of damage to a pavement structure, frost heaving decreases the design life of a structure, which increases the cost of either maintenance or replacement (U.S. Army and Air Force 1985). There are three necessary conditions for frost heaving: frost-susceptible soil, freezing temperatures, and the presence of water.

The frost-susceptibility of a soil depends on the amount of fines passing the no. 200 (0.074-mm) sieve. In particular, Casagrande (1931) found that he could index the frost-susceptibility of the soil as a function of the material finer than 0.02 mm. He found soils having greater than 3% of material finer than the 0.02-mm size appear to be highly frost-susceptible. In addition to having a frost-susceptible soil, freezing temperatures and a nearby source of water are also required for frost heave to occur. Based on the initial assessment of the Tilcon common granular fill material at CRREL, we found that the amount of fines passing the no. 200 sieve was approximately 20%, of which approximately 14% was finer than 0.02 mm (Fig. 1). The current COE frost-susceptibility criteria limits the amount of material finer than 0.02 mm to 3%. More explanation on the laboratory results for the Tilcon common granular fill are presented later.

LABORATORY TESTING

The Geotechnical Engineering Division at NED requested CRREL to perform laboratory testing to

determine the frost-susceptibility of material identified as Tilcon common granular fill. The testing procedure used at CRREL is ASTM D5918-96, *Standard Methods for Frost Heave and Thaw Weakening Susceptibility of Soils*. This is an index test for estimating the relative degree of frost-susceptibility of a soil. This procedure cannot be used to predict the actual amount of frost heave expected nor to predict the actual strength of the soil after thaw.

Two sets of tests were conducted to assess the present and future conditions of the subbase material. In one case, the specimens were compacted at the in-situ moisture content, then saturated. These samples are referred to as *saturated*. This case assumes that the subbase is saturated because of the infiltration of water into the pavement system, which may occur in the later life of the pavement due to cracking. In the second case, the specimens were compacted at the in-situ moisture content and no additional water was introduced during the testing. These samples are referred to as *unsaturated*. This case assumes that the pavement structure is not saturated, such as in the beginning of the pavement life.

Eight samples were prepared for testing. These samples were compacted at a density of 2.2 g/cm³ and a moisture content of 8%. The moisture-density data used were obtained from the NED Geotechnical Engineering Division. The samples are 146 mm in diameter and 150 mm in height. The compacted samples are confined in a split ring mold, which allows the samples to heave in an unrestricted manner.

For the saturated case, four samples were com-

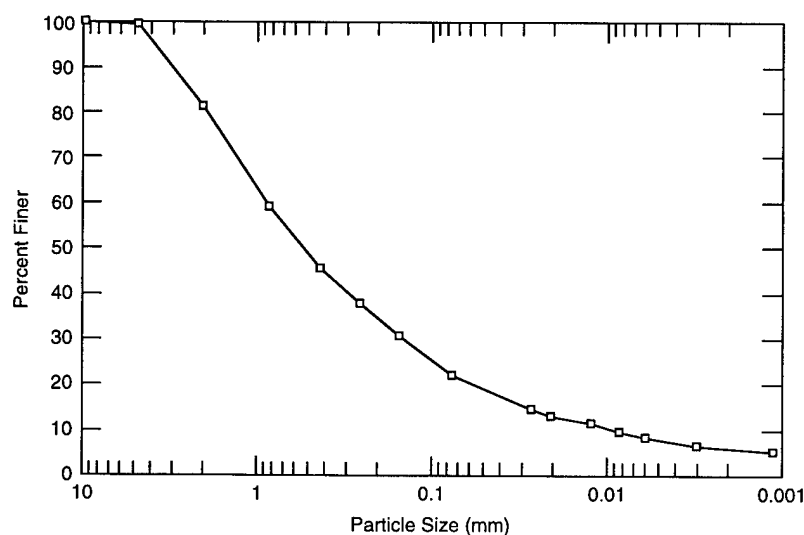


Figure 1. Grain size distribution for Tilcon common granular fill material.

pacted, then placed in the coldroom (3–4°C), and saturated by raising the water table at the rate of 25 mm/hour. The water table was maintained at the top of the samples overnight. The next morning, the water table was lowered to 10 mm above the sample bottoms and the samples were allowed to drain. All four samples had a constant water supply during testing. The specimens were then placed on the bottom warming/cooling plate. Thermocouples were installed in the samples at the top, bottom and depths of 25, 50, 75, 100, and 125 mm. The top cooling plates were placed on the samples along with a 5.5-kg surcharge weight that simulates the weight of a 150-mm-thick asphalt concrete pavement surface. The box was then filled with loose granular insulation.

The samples were conditioned at 3°C top and bottom for the first 24 hours. Following this conditioning period, the samples were subjected to four freeze–thaw cycles, rather than the ASTM standard of two cycles. Each freeze–thaw cycle consists of an initial 8-hour freeze of –3°C top and 3°C bottom. This is followed by a 16-hour freeze at –12°C top and 0°C bottom to freeze the entire sample from top to bottom. A 16-hour thaw period follows at 12°C top and 3°C bottom. At completion of the thaw, the samples are again stabilized at 3°C top and bottom for 8 hours before the next freeze begins.

Following the final thaw period, the samples were removed from the coldroom. California Bearing Ratio (CBR) tests (ASTM test method D1883) were conducted on the samples but limited to a penetration of 7.6 mm. The samples were then sliced horizontally into six approximately equal slices. The moisture content of these

slices was determined to develop a top-to-bottom moisture profile of each specimen.

CBR tests are an index of the shearing resistance of a soil or the soil strength. The test measures the strength of a soil for specific moisture and density conditions. The shearing resistance is obtained by forcing a steel piston into a compacted soil sample at the rate of 1.27 mm/minute. The force required to reach 2.54 mm and 5.08 mm of penetration is measured. The measured force is converted into a ratio and compared against standard test values to obtain the CBR. The CBR is not an exact measure of the shearing modulus because of a slight influence of the confining effect of the mold. CBR generally falls between 0 and 100% with a higher value, indicating a stronger soil. CBR testing was conducted before and after frost-susceptibility tests were run to determine the loss of strength in the Tilcon material. The results are given in Table 1.

The samples in the unsaturated case were prepared and tested in the same manner as the saturated samples with three exceptions: the samples were not saturated when placed in the coldroom, a constant water supply was not connected to the samples during testing, and due to time constraints, the unsaturated samples were only subjected to two freeze–thaw cycles. An illustration of the testing apparatus is shown in Figure 2.

Testing data were collected every 5 minutes by a Northgate 486DX2 computer. LabVIEW for Windows, Version 4, was used to control two Neslab RTE-110 circulating baths. The baths controlled the temperature of the top and bottom plates on the samples, which regulated the temperature gradient and the rate of freeze in the samples. The temperature data from each ther-

Table 1. Summary of Raymark test data.

Sample	Pretest moisture (%)	Post-test moisture (%)	Pretest density (g/cm ³)	Pretest CBR (%)	Post-test CBR (%)	Heave rate (mm/day)	Classification	Frost design classification*
1	7.66	10.33	2.26	45	4	20.2	Very high	F2
2	7.56	10.20	2.24	40	3	15.4	High	F2
3	7.11	10.04	2.45	43	3	15.0	High	F2
4	7.72	9.96	2.24	35	4	14.9	High	F2
5	8.35	7.91	2.25	44	10	6	Low	F2
6	8.25	8.03	2.26	45	9	4	Medium	F2
7	8.36	8.00	2.23	34	8	4	Medium	F2
8	8.77	8.12	2.24	39	9	4	Medium	F2

Note: Samples 1–4 are tested under saturated conditions; samples 5–8 are tested under in-situ conditions.

*An F2 classification indicates a frost-susceptible material with 6 to 15% of the material finer than 0.02 mm by weight (U.S. Army and the Air Force 1985).

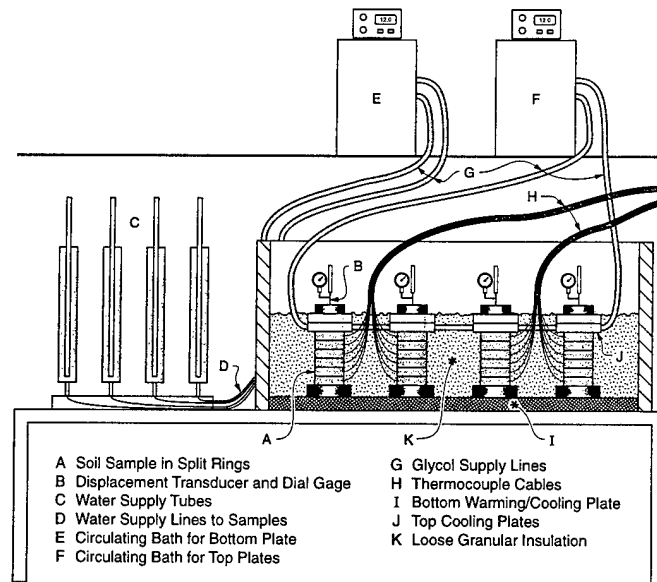


Figure 2. Laboratory testing apparatus.

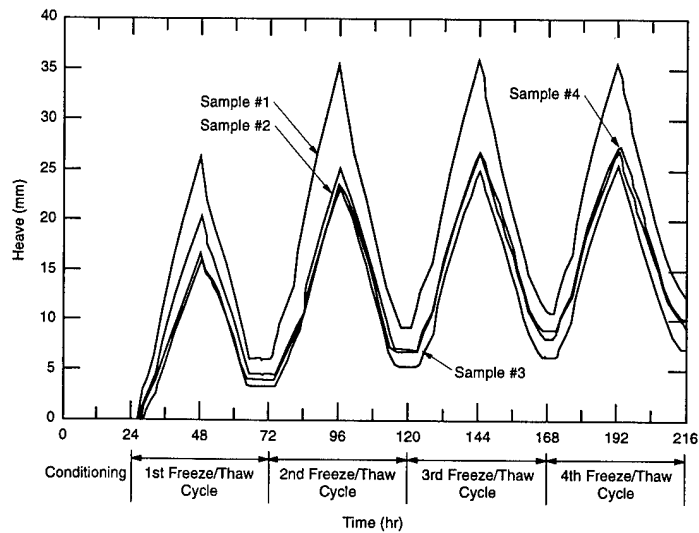


Figure 3. Frost-susceptibility testing for saturated soil samples.

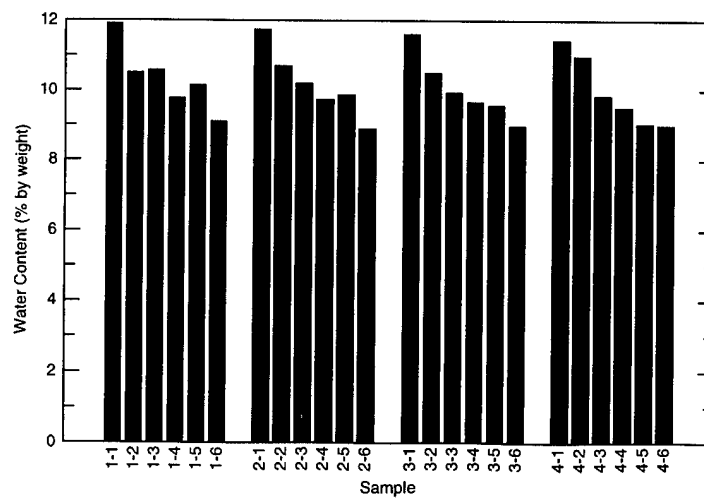


Figure 4. Sample moisture profile for saturated samples.

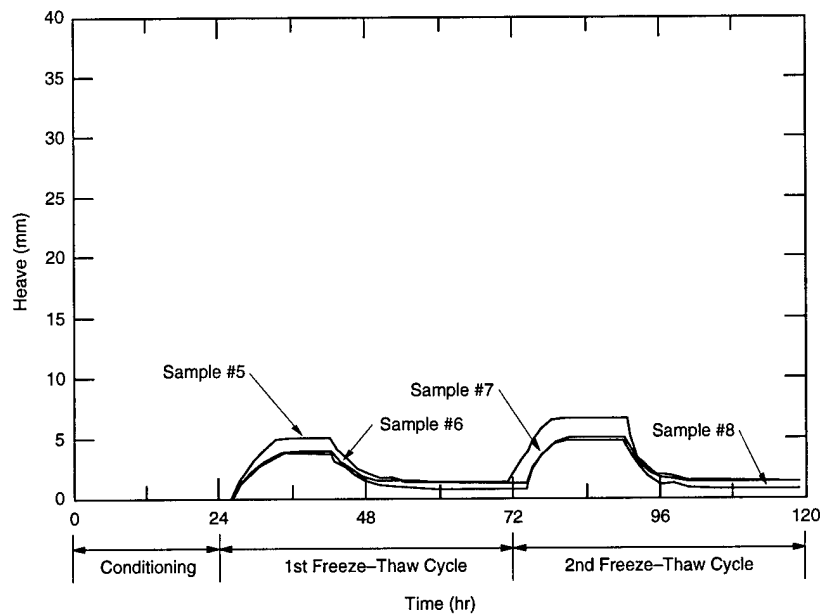


Figure 5. Frost-susceptibility testing for unsaturated soil samples.

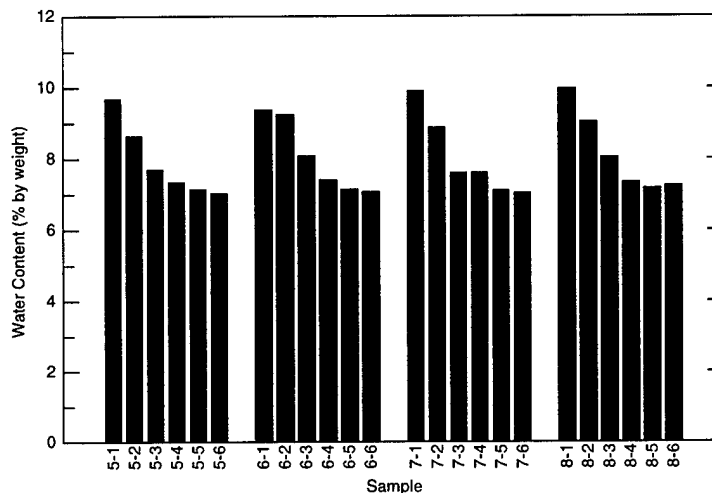


Figure 6. Sample moisture profile for unsaturated samples.

mocouple were collected hourly by a Campbell Scientific datalogger. This temperature data were used to monitor frost penetration (Fig. 3-6).

LABORATORY RESULTS

The results from the tests are shown in Table 1. The qualitative frost-susceptibility system is shown in Table 2. For the saturated Tilcon subbase soil, based on the rate of heave, the subbase material is classified as a high to very high frost-susceptible material. In the unsaturated condition, the material is classified as a low to medium frost-susceptible material.

COMPUTER SIMULATION

CRREL FROST model

The amount of frost heave expected at the Raymark site was predicted using the CRREL FROST model. This is a one-dimensional vertical heat and moisture flow model. The pavement structure, as shown in Figures 7-9, is discretized into nodes: up to 101 nodes or 100 elements. All the simulated pavement structures utilized a total of 94 nodes (or 93 elements). For ensured accuracy, node spacing in the freezing front is kept to 20 mm apart. The freezing front includes the pavement layers through the sand gas collection layer, below the geosynthetic liner materials. At

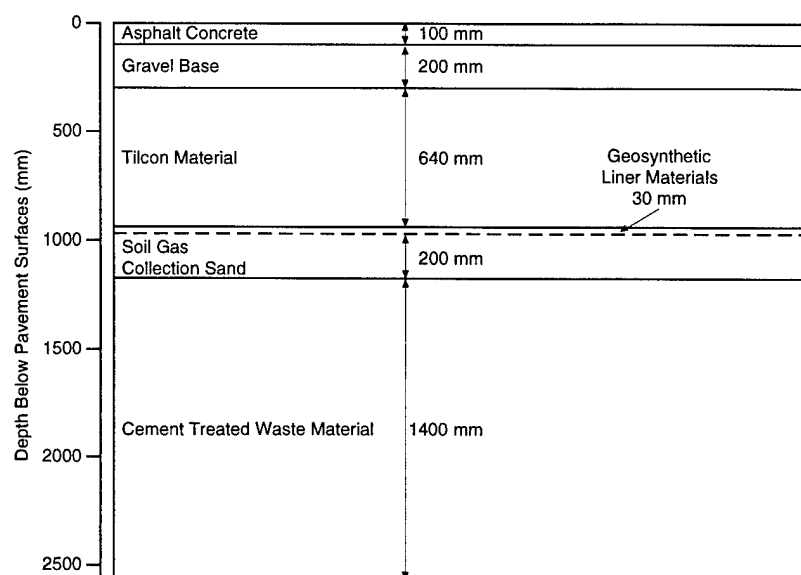


Figure 7. Pavement structure with 640-mm Tilcon layer modeled in FROST.

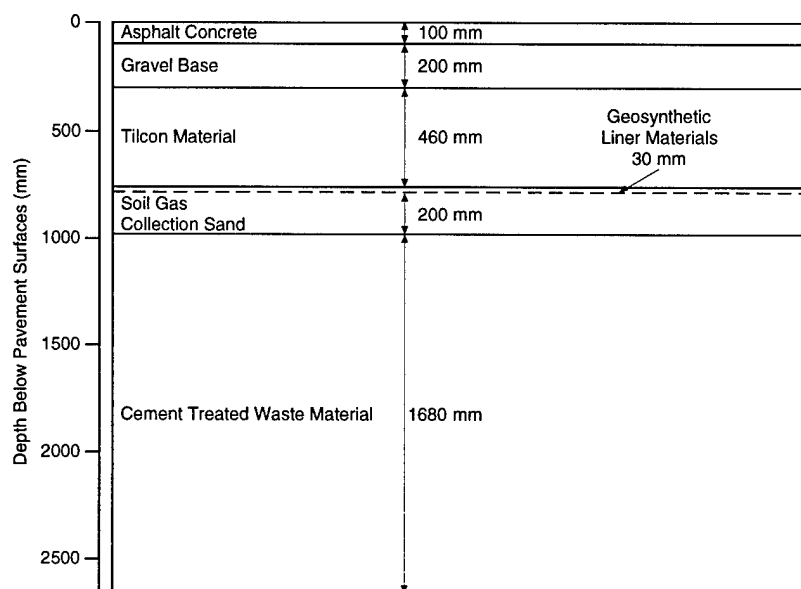


Figure 8. Pavement structure with 460-mm Tilcon layer modeled in FROST.

Table 2. Criteria for determining frost-susceptibility test.*

Frost-susceptibility classification	Symbol	8-hour heave rate (mm/day)	Bearing ratio after thaw (%)
Negligible	NFS	<1	>20
Very Low	VL	1 to 2	20 to 15
Low	L	2 to 4	15 to 10
Medium	M	4 to 8	10 to 5
High	H	8 to 16	5 to 2
Very High	VH	>16	<2

*Typical CBR for fine-grained soils such as clays, silts, and fine sands usually range between 3% to 15%. Coarser materials (sand-silt-clay combinations and gravelly sand) range from 10% to 40%. Gravelly clays, gravel-sand mixtures, and well-graded gravels can range between a CBR of 20% to 80%.

depths farther from the freezing front, the node spacing can be farther apart without loss of accuracy. The nodes were spaced 40 mm apart through the subgrade layer of the waste material. Tables 3–5 show the number of elemental lengths used in each layer in all the simulations.

The first two computer simulations were designed to predict the frost effects in the pavement structure with the Tilcon common granular fill material through the freezing season. As shown in the laboratory frost heave tests, the Tilcon material, when saturated, may be considered a highly frost-susceptible material. Since the graded aggregate base has a lower frost-susceptibility, the depth was increased from 203 to 560 mm to

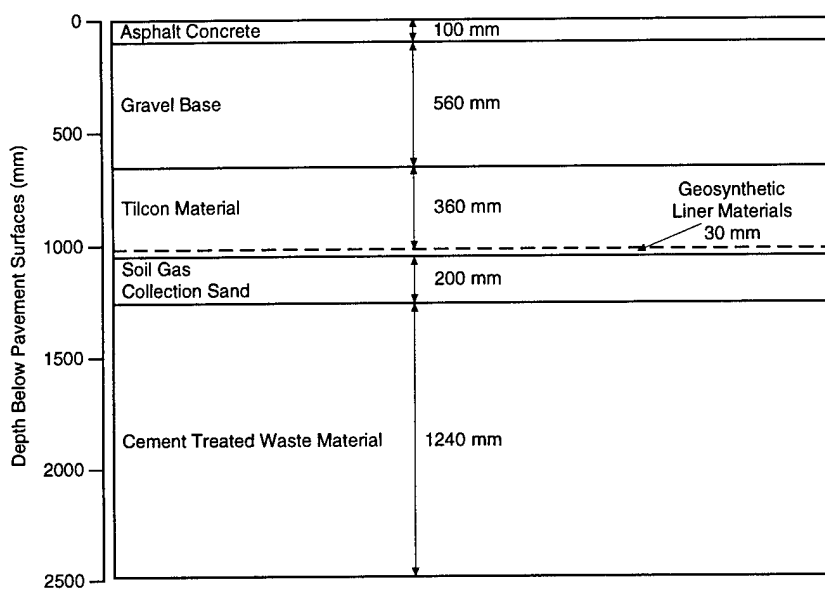


Figure 9. Pavement structure with 560-mm graded base modeled in FROST.

Table 3. Distribution of elements through pavement structure, 640-mm Tilcon subbase layer.

Layer number	Layer type	Thickness of layer (mm)	Number of elements
1	Asphalt concrete	100	5
2	Graded aggregate base	200	10
3	Tilcon common granular fill	640	32
4	Geosynthetic liner materials	30	1
5	Soil gas collection sand	200	10
6	Cement-treated waste material	1400	35
Total		2570	93

Table 5. Distribution of elements through pavement structure, 560-mm base course layer.

Layer number	Layer type	Thickness of layer (mm)	Number of elements
1	Asphalt concrete	100	5
2	Graded aggregate base	560	28
3	Tilcon common granular fill	360	18
4	Geosynthetic liner materials	30	1
5	Soil gas collection sand	200	10
6	Cement-treated waste material	1240	31
Total		2490	93

Table 4. Distribution of elements through pavement structure, 460-mm Tilcon subbase layer.

Layer number	Layer type	Thickness of layer (mm)	Number of elements
1	Asphalt concrete	100	5
2	Graded aggregate base	200	10
3	Tilcon common granular fill	460	23
4	Geosynthetic liner materials	30	1
5	Soil gas collection sand	200	10
6	Cement-treated waste material	1680	44
Total		2670	93

determine the effects in the third set of computer simulations.

Inputs into the FROST model include layer thickness, soil type, soil parameters, water table location, and air temperature data. FROST then calculates the soil temperature, moisture stress, water content, ice content, and density for each node at each designated time step throughout the simulation period. Output from FROST contains a daily prediction of the cumulative frost heave,

the estimated rate of frost heave, and both the frost and thaw depths. Details of the model are addressed in Guymon et al. (1993). Further explanation of the input parameters as applied to the Raymark Superfund site is given below.

Layer thickness

Typically, frost penetration occurs in the base layers, but it may also occur in the subgrade layer. Increasing the thickness of the base will typically minimize the amount of frost heave. This is the intent of the last set of computer simulations where the graded aggregate base layer was increased from 200 to 560 mm.

The pavement structures in which the thickness of the Tilcon subbase layer was varied to see the effects on frost heave and penetration. The first uses a 640-mm subbase layer of Tilcon common granular fill below a 200-mm graded aggregate base layer. The second pavement structure decreases the Tilcon subbase layer from 640 to 460 mm.

Soil type and soil properties

Since laboratory tests were not conducted on the materials currently in use for the pavement structure at the Raymark site, thermal and hydraulic properties were estimated from CRREL's soil database. Therefore, the results of all of the simulations are a best estimate from the limited amount of information on the material properties.

Table 6 provides a summary of the soil types currently in use for the Raymark Superfund site, and the soil types used in all of the computer simulations. It should be noted that the model used a low to medium frost-susceptible material as the graded aggregate base. The Tilcon common granular fill material was modeled as a well-graded sandy material and the geosynthetic liner materials were modeled using a clay material. The clay was selected because for its low permeability and is most similar to the impermeable features of the geosynthetic liner materials.

at the Raymark Superfund site, groundwater is not a factor. Instead, the concern is the infiltration of moisture, from either precipitation or snow-melt, through the pavement surface into the base and subbase layers. To meet these criteria, all of the pavement structures were also modeled using a shallow (100-mm) water table and a deep (2740-mm) water table.

The deep water table represents the current in-situ moisture content of the soil on site, and will be referred to as either *moist soil* or *low moisture content* throughout this report. This is also a reasonable scenario for a new pavement structure. By locating the water table at a depth far from the freezing front, the suction of moisture to the surface during freezing is minimal. This scenario also assumes the pavement structure does not permit infiltration of water through the asphalt and into the underlying layers. The shallow water table, on the other hand, represents an older pave-

Table 6. Summary of soils used in FROST model for simulation.

Soil parameters used in FROST model	Material layer					
	Asphalt concrete	Graded aggregate base GW*	Tilcon common granular fill SM	Geosynthetic liner materials CL	Soil gas collection sand GP	Cement- treated waste SP
Soil density (g/cm ³)	2.3	1.84	1.551	1.69	2.16	1.61
Soil porosity (cm ³ /cm ³)	0.14	0.3311	0.419	0.374	0.2	0.436
Saturated hydraulic conductivity (cm/hr)	2.1	4.7	1.6	0.14	0.46	8.1
Unfrozen volumetric water content (cm ³ /cm ³)	0.039	0.016189	0.03602	0.2916	0.0566	0.0198

* Modeled materials (Unified Soil Symbol).

The CRREL soil database does not contain any properties on stabilized materials. To model the waste material, a poorly graded sand material was selected (denoted by the SP classification). With respect to frost heave, the pores in the stabilized material are filled with some form of stabilizing agent. In the case of the Raymark Superfund site, the stabilizing agent is cement. The addition of the stabilizing agent makes the soil impermeable and less prone to frost heave. The poorly graded sand material was chosen because it had a high porosity that reduces capillary action in the soil, thereby reducing frost heave.

Water table depth

Typically, in a FROST simulation, the location of the water table below the pavement surface will have an impact on the computer results. However,

ment where moisture infiltration occurs through cracks in the surface layer. This scenario assumes that the subsurface layers 100 mm below the surface are completely saturated, even during freezing. This scenario will be referred to as either the *fully saturated* or *saturated* case throughout this report.

Temperature data

In addition to the material properties, the air temperature during the freezing season is required as input for the model. The air temperatures were selected based on the design freezing index (DFI) (Johnson et al. 1975). Daily minimum and maximum temperatures from 1965–1996 recorded from the Bridgeport Airport were used to determine the DFI. This weather station is the closest to the Raymark Superfund site in Strat-

Table 7. Example of determining cumulative degree-days.

Day	Average daily temperature (°C)	Degree-days (°C-d)	Cumulative degree-days
1	8	+8	8
2	10	+10	18
3	9	+9	27
4	5	+5	32
5	3	+3	35
6	2	+2	37

ford, Connecticut. For each freezing season, which typically ranged from 1 November through 31 March, an average daily temperature (°C) was determined and used to calculate cumu-

lative degree-days. A degree-day is negative when the average daily temperature is below 0°C and positive when the average daily temperature is above 0°C (Johnson et al. 1975). An example of the cumulative degree-day calculation is shown in Table 7. A typical curve of cumulative degree days as a function of the freezing season for Bridgeport, Connecticut, is shown in Figure 10. This freezing curve illustrates the period of time prior to and throughout the freezing season until thaw occurs. The annual freezing index (AFI) is the numeric difference between the maximum and minimum locations of the curve. A larger AFI value indicates a season with lower temperatures. For Bridgeport, the three highest AFI values occurred in 1993–94 (291), 1977–78 (272), and

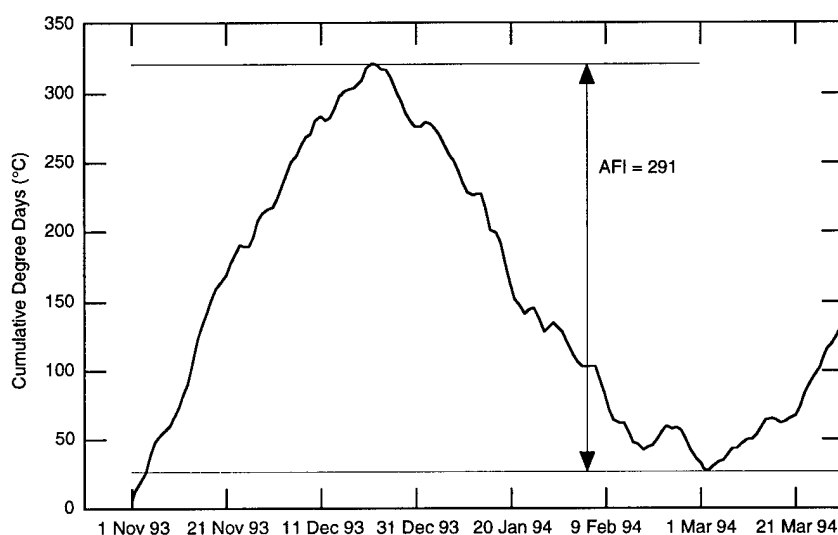


Figure 10. Annual freezing index curve for 1993–94 freezing season.

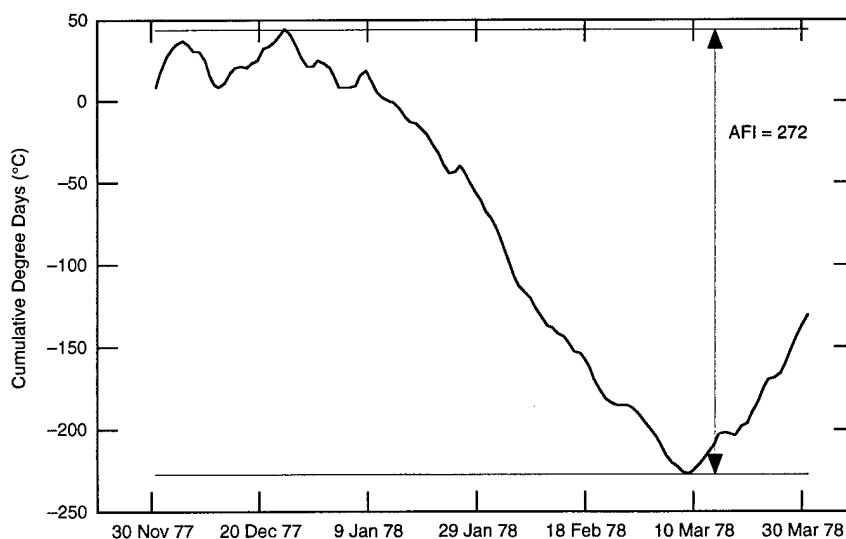


Figure 11. Annual freezing index curve for 1977–78 freezing season.

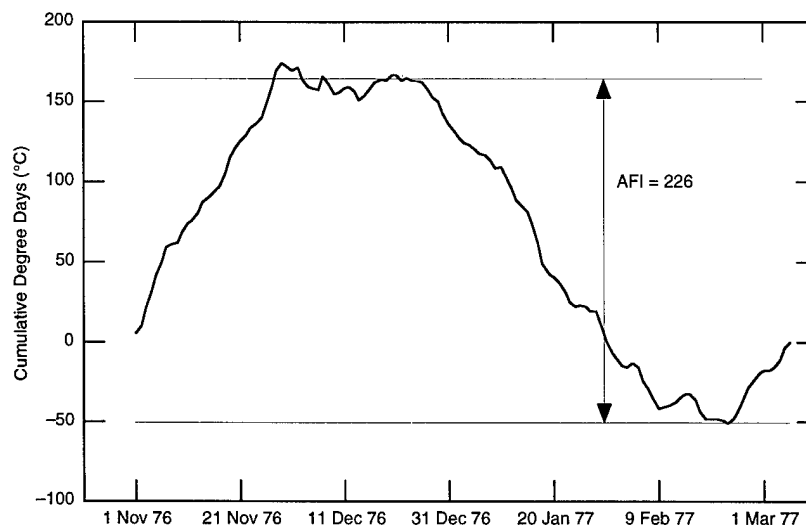


Figure 12. Annual freezing index curve for 1976-77 freezing season.

Table 8. Determination of DFI.

Coldest freezing seasons	AFI value
1993-94	291
1977-78	272
1976-77	226
Average of three AFI values:	263
Freezing season closest to average:	1977-78

1976-77 (226) (Fig. 10-12). The average of these three coldest freezing seasons was calculated and the single season with an AFI value closest to the average AFI is used in the simulations (see Table 8). The DFI is calculated by averaging the values of the three coldest freezing seasons.

The DFI value was calculated at 263°C-days. The 1977-78 freezing season, with an AFI value of

272°C-days, corresponded the closest to the DFI. The temperature data from the 1977-78 season were used in the computer simulation (Fig. 13). It should be noted that the temperature data used in the computer simulation is slightly colder than the calculated DFI value. This provides a more conservative estimate for the prediction of frost penetration on the pavement structure. The simulation was run over a 151-day period, simulating the freezing season from 1 November through 31 March.

COMPUTER SIMULATION RESULTS

640-mm Tilcon subbase material thickness

Both the input and the output files for the

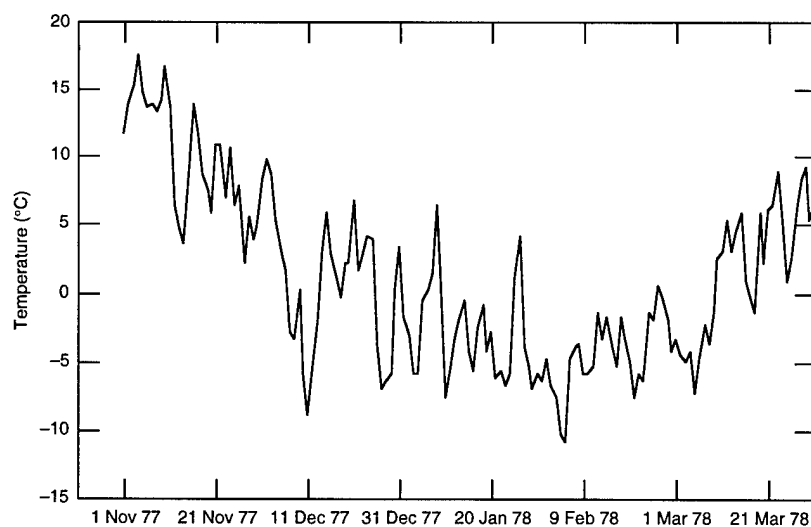


Figure 13. Average daily temperature curve for 1977-78 freezing season.

640-mm Tilcon common granular fill subbase layer for both the in-situ and saturated moisture conditions are presented in Appendices B and C in Internal Report 1179.* The upper layers of this pavement structure included 100 mm of asphalt, 200 mm of graded aggregate base, and 640 mm of Tilcon common granular fill. The output from FROST provides daily cumulative minimum, maximum, and mean estimates for frost heave, as well as estimates for both the frost and thaw depth. Results for frost heave are shown in Figure 14. When the water table was placed 2740 mm below the surface, simulating a pavement with a low moisture content, the cumulative heave was 3.8 mm. This may be considered a low amount of frost heave. When the water table was located 100 mm below the pavement surface, simulating a fully saturated soil, the maximum cumulative

mean heave for the Raymark site during a single freeze-thaw cycle was approximately 68 mm. The predicted amount of heave could be classified as high when the soil was modeled under fully saturated conditions.

Predictions of frost penetration into the soil during the freezing season reached 500 mm with a moist soil, and 320 mm with a saturated soil (Fig. 15). The frost depth penetrates to a maximum depth of 200 mm into the Tilcon material layer, less than halfway through the layer, and does not extend down to the geosynthetic liner.

460-mm Tilcon material thickness

At the request of NED, a computer simulation using 100 mm of asphalt concrete, 200 mm of graded aggregate base and 460 mm of the Tilcon common granular fill was run. This scenario was

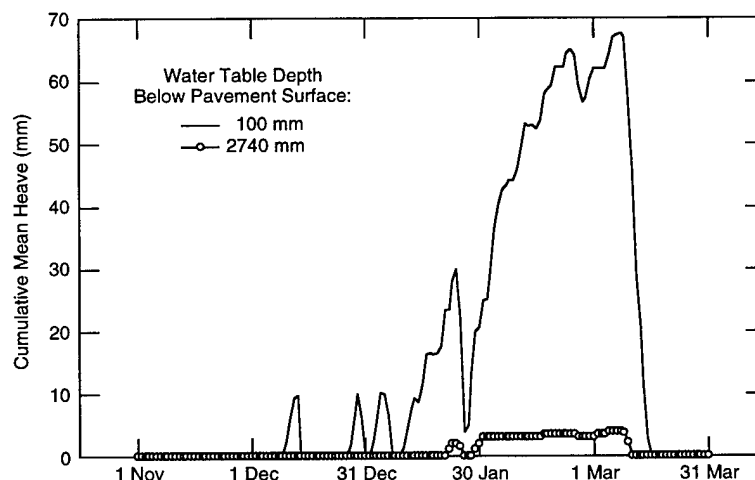


Figure 14. FROST prediction of cumulative mean heave—640-mm subbase layer.

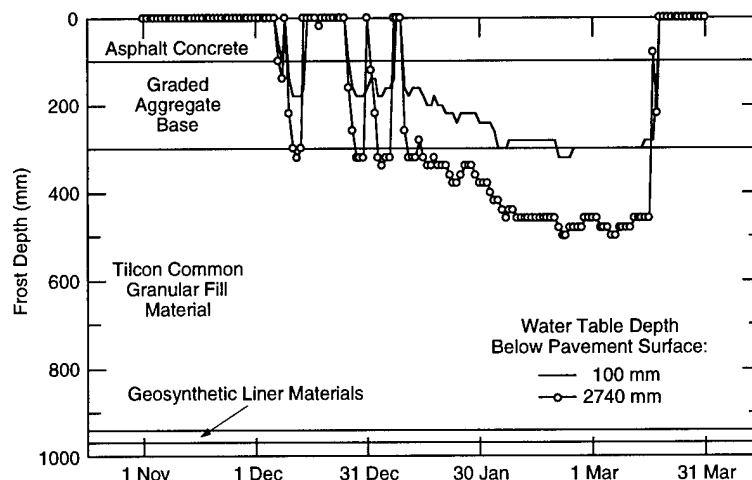


Figure 15. FROST prediction of frost penetration—640-mm subbase layer.

* Internal Report 1179 is available from the authors.

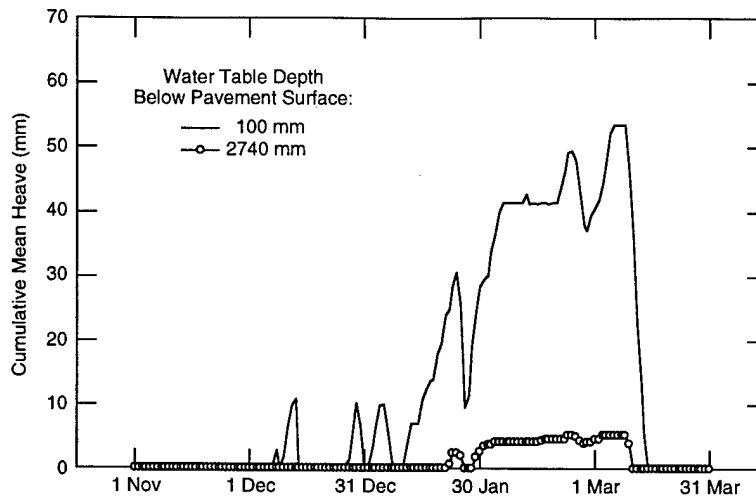


Figure 16. FROST prediction of cumulative mean heave—460-mm subbase layer.

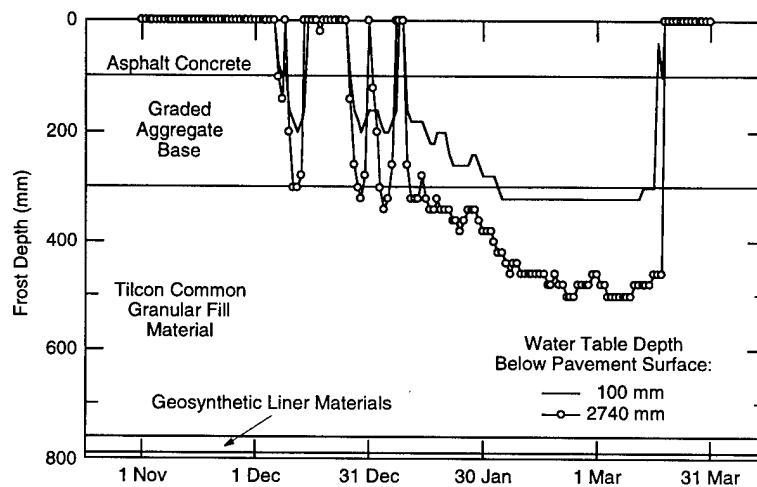


Figure 17. FROST prediction of frost penetration—460-mm subbase layer.

created to see how great an effect a reduced subbase thickness would have on frost heave and penetration. The input and output files for both moisture contents are included in Appendices D and E in Internal Report 1179. Results for the predicted frost heave are given in Figure 16. For frost heave, decreasing the thickness of the Tilcon material layer containing a moist soil increased the amount of expected frost heave to 5.1 mm. Even with this increase, the frost heave is still classified as low. For the saturated soil, the predicted amount of frost heave was 53 mm.

Even with a decrease in the Tilcon layer of 180 mm, frost penetration remained the same. Estimated frost depths were 500 mm for a moist soil and 320 mm under saturated soil conditions (Fig. 17).

560-mm graded aggregate base thickness

The results of the simulation using 560 mm of graded aggregate base estimated that no frost heave would occur under in-situ conditions. The results using a saturated structure show that the estimated frost heave is 61 mm (Fig. 18). Frost penetration, under in-situ conditions, is estimated to reach 680 mm. This depth reaches into the very top of the subgrade. For the saturated conditions, the frost depth only reaches 280 mm (Fig. 19). This frost depth is 40 mm less than either of the first simulations. Appendices F and G in Internal Report 1179 contain the input and output files for this simulation. Table 9 provides a summary of the computer simulations.

Table 9 illustrates that a reduction in frost heave occurs when a thicker aggregate base layer composed of relatively non-frost-susceptible

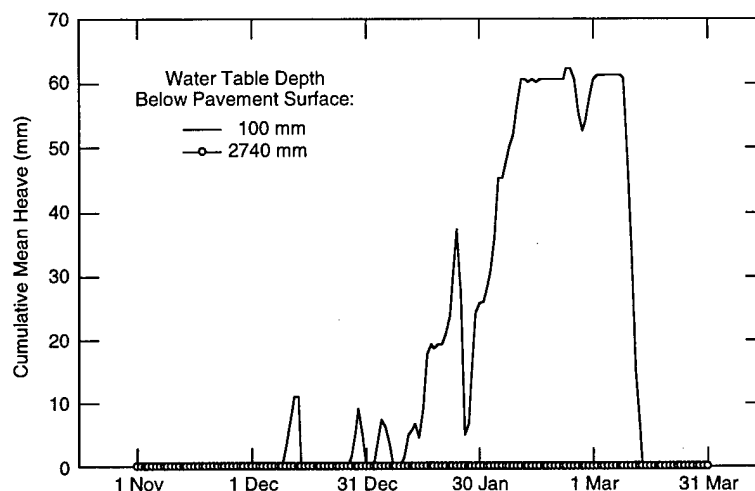


Figure 18. FROST prediction of cumulative mean heave—560-mm base layer.

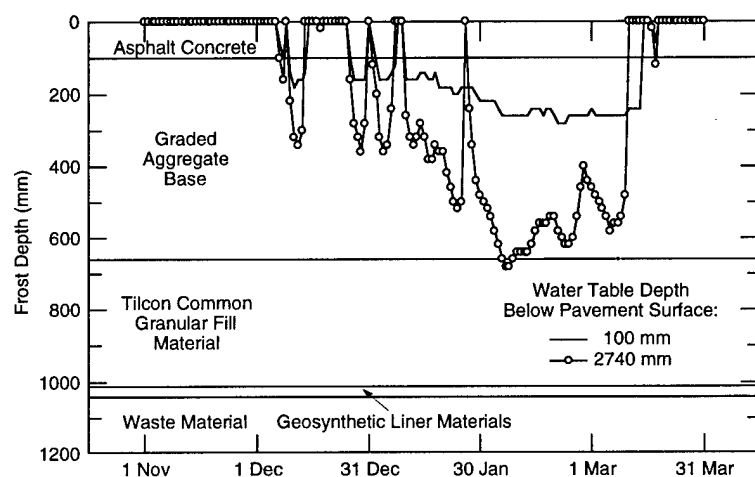


Figure 19. FROST prediction of frost penetration—560-mm base layer.

Table 9. Summary of frost heave and frost depth predictions from computer simulation.

Pavement structure with 100-mm asphalt concrete over 200 mm of graded aggregate base

Thickness (mm)	2740-mm water table depth		100-mm water table depth	
	Frost heave (mm)	Frost depth (mm)	Frost heave (mm)	Frost depth (mm)
Tilcon common granular fill				
640	3.8	500	68	320
460	5.1	500	53	320

Pavement structure with 100-mm asphalt concrete over 560 mm of graded aggregate base

Graded aggregate base				
560	0.0	680	61	280

material is used under in-situ conditions. Under saturated moisture conditions, the amount of frost heave and frost depth is approximately the same for all of the computer simulations. This may be the case if the pavement layer is cracked and water and fine material are allowed to flow into the base/subbase layer and the pavement structure should become fully saturated.

One of the problems with the FROST model is that it is unable to account for drainage during the frost heave process. Materials that have a low amount of fines passing the 0.074-mm sieve will drain and have less suction to draw water toward the freezing front.

To further study the effect of increasing the base course layer to 560 mm, the simulations were run again, and the water table was placed at a depth of 940 mm below the surface of the pavement for both the structure using 640 mm of Tilton fill and the structure using 560 mm of graded aggregate base (Fig. 7 and 9). The results from these simulations showed no frost heave occurring in the 560-mm graded aggregate base course structure.

CUMULATIVE DAMAGE

Pavement structures will degrade over time due to frost heave and thaw weakening, and the anticipated loading from traffic. A damage model can be used to predict the rate of this degradation. The pavement design specifications proposed for the Raymark Superfund site for heavy-duty traffic was based on a design life of 20 years, and estimating an equivalent axle load (EAL) between 7.0 and 46.0 per day. The CRREL SLED model (Seasonal Layered Elastic Design) was used to create a multilayered pavement structure, which estimated strain values at the bottom of the pavement layer and the top of the subgrade layer. SLED is composed of four computer programs. The first program is FROST, which estimates frost heave and frost depths. TRANSFRM uses the daily output from FROST to produce output files of layered pavement systems with estimated modulus values. The output files from TRANSFRM are used as input into NELAPAV (Nonlinear Elastic Layer Analysis for PAVements), which calculates the strains within a layered pavement system (Irwin and Speck 1986). Finally, damage estimations were calculated using the Shell damage model (Huang 1993). The Shell damage model uses the following equations:

$$Damage = \frac{Number\ of\ Applications}{N_{design}} \quad (1)$$

where *Number of Applications* is the design applications, where N_{design} for the bottom of the pavement is calculated using

$$N_{design} = 0.0685(Strain_{horizontal})^{-5.671}(M_r)^{-2.363} \quad (2)$$

where N_{design} = the number of calculated applications

$Strain_{horizontal}$ = the calculated tensile strain

M_r = modulus value of the material (psi).

N_{design} for the top of the subgrade is calculated using

$$N_{design} = 1.94 \times 10^{-7}(Strain_{vertical})^{-4.0} \quad (3)$$

where $Strain_{vertical}$ is the calculated compressive strain.

Damage calculations were only performed on the 560-mm base course pavement structure, since this structure is representative of the specified design. It should be noted that only the structure simulating moist (not saturated conditions) was investigated.

Estimated damage is calculated on a daily basis and summed for a 1-year period to obtain a total estimate of damage to the pavement structure (otherwise known as Miner's rule). Using this, failure occurs when *Damage* equals or exceeds 1.0. Therefore, for a section to last its design life, the value of the calculated damage value should not accumulate to 1.0 until the design period expires. *Damage* was calculated based on both 7 and 46 EALs per day. The estimated amount of cumulative damage calculated in the first year using 46 EALs per day was 0.0076 at the bottom of the pavement and 0.001 at the top of the subgrade (Fig. 20 and 21). Based on a linear summation of daily damage, the results suggest that the pavement structure will not fail from either fatigue nor subgrade rutting during its design life. Results of the damage calculations are given in Appendix H in Internal Report 1179.

CONCLUSIONS

Laboratory frost heave tests indicate that the Tilton common granular fill may be classified as of low to medium frost-susceptibility. However, if the material becomes saturated, the tests indicate that the material is highly frost-susceptible.

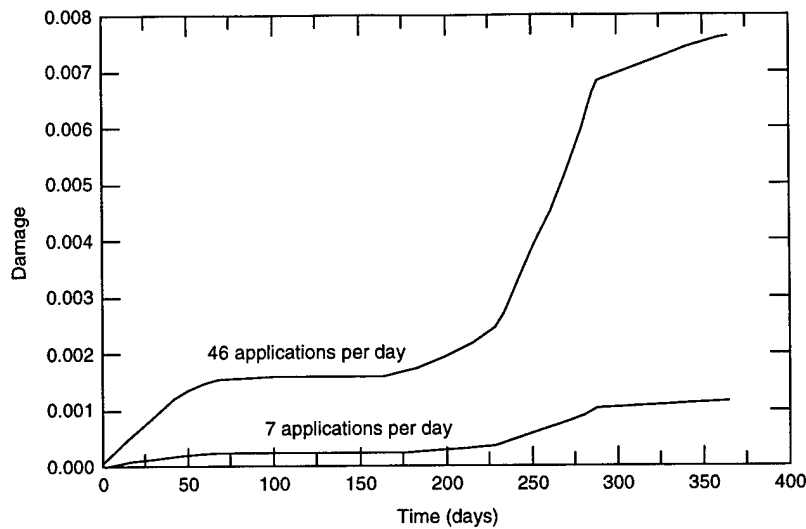


Figure 20. Cumulative damage for first year—at bottom of pavement.

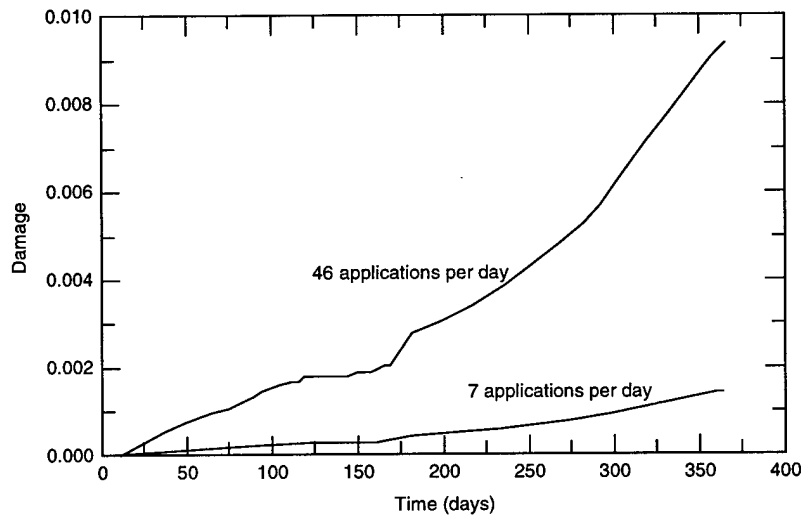


Figure 21. Cumulative damage for first year—at top of subgrade.

The results from the computer simulations agree with the laboratory findings. Estimates of frost heave based on the CRREL FROST model and assumed material properties indicate very minimal frost heave (< 10 mm) under in-situ moisture conditions. If for some unforeseen reasons, the pavement structure soil becomes saturated, as demonstrated by modeling a worst case scenario, the amount of frost heave estimated was in the vicinity of 50–70 mm.

Finally, the results from the damage calculations suggest that the pavement structure will not fail from either fatigue or subgrade rutting during its design life.

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13. ABSTRACT (Maximum 200 words) This project was conducted to assist in predicting the effects of freeze-thaw cycling on Tilcon common granular fill during the freezing season. This material is being used as the subbase material in the proposed pavement structure at the Raymark Superfund site in Stratford, Connecticut. Based on the initial laboratory results of the Tilcon material performed at CRREL, the amount of fines passing the no. 200 sieve was found to be in the vicinity of 20%, of which approximately 14% was finer than 0.02 m. Results from the frost heave tests indicate that when the Tilcon material is saturated, based on the rate of heave, the material is classified a high to very high frost-susceptible material. In the saturated condition, the material is classified as a low to medium frost-susceptible material. Computer simulations were run to predict the amount of frost heave and frost penetration that may be expected on this site during the freezing season. Results from the laboratory frost-susceptibility tests and computer simulations were then used to estimate the amount of cumulative damage to the pavement structure during its design life.					
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